ADAPTIVE MANUFACTURING: ENABLING THE LEAN SIX SIGMA ENTERPRISE

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EXECUTIVE SUMMARY

Manufacturing continues to become a commodity within the value chain. That fact is indisputable. The greater the rate of manufacturing commoditization, the greater the focus on creating efficiencies that drive down product costs. From the world's largest computer manufacturer to the world's largest automotive manufacturer, companies that create value that are orders of magnitude greater than their competitors do so because they relentlessly focus on "leaning" their manufacturing operations without compromising their ability to adapt dynamically to the vicissitudes of their markets.

Given the current pressure on product margins, lean manufacturing principles provide an excellent framework for squeezing costs out of manufacturing. Lean manufacturing principles provide a strong foundation to support many manufacturing methods, including make to order, assemble to order, repetitive manufacturing, and a host of other methods. However, lean manufacturing by itself is not enough for success. With today's volatile demand and fragmented supply environments, you must combine lean manufacturing principles with the principles of six sigma so you can understand and address the causes of variability and better manage exceptions.

However indisputable the benefits of lean manufacturing and six sigma, in today's fast-moving, complex business environment, you must continually adapt. You must do so by handling large amounts of data and executing complex workflows while electronically communicating any exceptions simultaneously to multiple locations. In an environment like this, you need enabling software applications and a stable technology platform. Without IT, your organization can't be a truly lean or six sigma enterprise. To create an adaptive manufacturing environment, you must be able to access real-time information from the plant floor and the supply chain and then use this information to manage exceptions with enterprise resource planning (ERP) and supply chain management (SCM) applications.

Enabling lean manufacturing and six sigma principles to improve operations requires a nontraditional approach. The old idea that lean manufacturing and six sigma principles don't require IT just isn't valid anymore. ERP and SCM applications are critical for enabling a holistic, lean manufacturing operation, and they work hand in hand to better enable consumption − not forecasts − to drive replenishment.

SAP® solutions support both lean manufacturing and six sigma principles so you can intelligently adapt to exceptions and build a lean and six sigma–compliant enterprise that lays the foundation for value creation.

REAL-WORLD AWARENESS: MAKING LEAN LEANER

Since the start of the industrial age, every profitable manufacturer has done one thing very well: manufacturing at lower costs. As manufacturing continues to become a commodity, companies need leaner manufacturing processes to keep product costs down without compromising quality just to stay competitive. The implicit objective has always been to become leaner faster than the competition. James P. Womack, in his epic book *The Machine that Changed the World*, states that lean production is "lean" because it uses less of everything compared with mass production: half the human effort in the factory, half the factory space, half the investment in tools, half the engineering hours to develop a new product in half the time, and far less than half of the needed inventory on-site. The manufacturers that succeed are the ones that use resources more productively.

But the leaner the system, the more susceptible it is to exceptions. Using less of everything implies less inventory, less capacity, and fewer resources to fall back upon, so using less of everything is easier said than done. In the real world, it's impossible to anticipate every contingency. There's no guarantee that something will not be inconsistent with the plan. The leaner the system, the greater the possibility of destabilization and the greater the need to adapt rapidly. Adaptability requires **awareness** – knowledge of the environment and, more importantly, an understanding of the context. The more real time this awareness, the greater the relative benefit. The ability to connect and sense information in real time from people, IT sources, and physical objects within manufacturing and across the supply chain using technologies that enable quick, effective responses is what drives real-world awareness. It is crucial to the success for any lean manufacturing initiative.

The lack of connectivity with environments that are aware of the real world has prevented lean manufacturing practices from catching on the way experts have been predicting for the last two decades. Numerous studies of lean manufacturing transformations have shown enormous benefits: capacity utilization increased by over 90%, quality improved by 100%, space utilization reduced by 50%, customer service improved by 200%, inventory reduced by over 50%, and unit costs reduced by 30% to 100%. Nevertheless, manufacturers have struggled to understand and implement lean manufacturing principles.

The question that therefore arises is this: have manufacturers failed in their pursuit of lean production techniques? That notion is hard to support, especially given the tremendous improvements in overall manufacturing productivity in the United States and other economies during the late 1990s – a significant 2% increase that U.S. Federal Reserve Board Chairman Alan Greenspan attributed to the broad impact of information systems. Clearly, there have been successes. But the need to institutionalize a systematic program for lean manufacturing has never been greater. This is especially true as U.S. and European manufacturers come to grips with the harsh realities of global manufacturing – competitors from the East, unencumbered by past practices, have caught up and are surging ahead.

Lean manufacturing techniques may be insufficient to stem this trend, but lean manufacturing is a competitive necessity for any company that believes manufacturing is core to its success. Lean manufacturing is no longer an option. It is a must.

A More Pragmatic Approach to Lean Manufacturing

Lean manufacturing practices have been around for more than two decades, but the old paradigms of lean are not as applicable today as they were in the past. Lean manufacturing was originally based on two core assumptions: low demand variability (to ensure a smooth production schedule) and local suppliers (to ensure short lead times and just-in-time, or JIT, deliveries).

Neither of these assumptions holds today. Demand variability continues to rise, and supply chains are increasingly fragmented, with suppliers distributed all over the world.

Consider some of the reasons for demand variability. Consumers today are less brand loyal than they ever were. They have less time for shopping. According to one study, if the product consumers wanted wasn't there, 20% of the time they chose another brand, and 30% of the time they went to another retailer. In addition, consumers have more information available (often via the Internet) to compare products, and there is an ever-increasing stream of targeted promotions. More products are introduced faster, further expanding the choices available to consumers.

The tremendous efflux of supplier bases from expensive plants in the United States and Europe to parts of the world with lower labor costs has fragmented the supplier base. This phenomenon will accelerate in the years to come as overseas manufacturers move up the productivity learning curve, leaving many developed nation manufacturers flat footed. According to the Boston Consulting Group, industrial goods will travel the same path as consumer goods did over the 20 years. According to its research, in the United States, 70% of footwear, 60% of audio and video equipment, and 45% of apparel come from countries with low-cost labor. The Boston-based management consulting firm figures that industrial goods sourced from suppliers beyond U.S. borders account for more than 10% of U.S. industrial consumption and will grow at the rate of 30% per year – even in a flat economy.

Demand variability and supplier fragmentation have blurred visibility through the supply network. To operate in this environment, you require new levels of awareness within your manufacturing operations, and lean manufacturing principles will have to adapt to the new realities.

Figure 1: Blurred Supply, Demand, and Operations Visibility

Today, lean principles extend well beyond manufacturing. Successful companies will extend lean processes and techniques upstream and downstream in their supply network to suppliers and customers. To operate in such a volatile environment, new lean practices need to be augmented by some fundamental changes to make companies more aware of the real world:

- Lean manufacturing needs to be a part of an overall strategic initiative; it simply can't be a stand-alone initiative.
- Lean is not just about manufacturing. The principles can and must be applied to all supply chain network operations.
- Lean is necessary, but not sufficient in a high-velocity environment with large demand fluctuations and a distributed supplier base. Adapting to fluctuations is key.
- Lean can't be just about processes. It must be backed by enabling technology like ERP and SCM that makes lean principles broadly applicable and, more importantly, scalable.
- Lean principles must blend with six sigma processes. Lean techniques reduce waste; six sigma techniques reduce variation in processes, which in turn drives new levels of lean production.

Blurred demand and supply introduce a large degree of variability into manufacturing and supply chain operations. Real-world awareness enables you to be more adaptive and to manage unanticipated exceptions while keeping the core lean principle (waste reduction) intact. In an environment that is aware of the real world, manufacturing processes need to be continually monitored, reviewed, reworked, and improved, and this is where the principles of six sigma can help. Companies that make manufacturing a competitive differentiator will use real-world awareness capabilities to enable adaptive manufacturing practices. These practices will then further enable lean- and six sigma-based manufacturing processes.

ADAPTIVE MANUFACTURING ENABLES THE LEAN SIX SIGMA ENTERPRISE

Lean principles focus on providing value to customers and on eliminating all waste in manufacturing. Six sigma principles focus on reducing variability in value-added activities (process and product), which improve quality without incurring additional costs.

Institutionalizing a cyclical process that eliminates waste and improves quality (see Figure 2), not only reduces lead times and inventory, it also reduces variability and creates more uniform output. Successful manufacturers continuously tighten the loop that reduces waste (lean manufacturing) and reduces variability (six sigma), while increasing the velocity with which they create value. This virtuous cycle enables the lean six sigma enterprise.
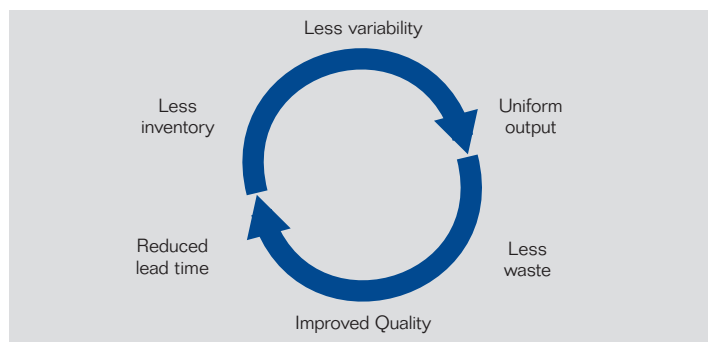
Figure 2: The Virtuous Lean Six Sigma Cycle Reduces Waste and Variability in Manufacturing

When working in unison, lean and six sigma principles present a formidable response to waste and variation. Within this natural marriage between two philosophies, lean techniques create the standard, and six sigma techniques investigate variations from the standard. However, while these principles add tremendous value and are essential ingredients to drive manufacturing cost and time efficiencies, by themselves they don't provide enough flexibility to allow you to respond to demand and supply uncertainties. That's why you need to implement adaptive manufacturing while still retaining lean and six sigma practices.

Adaptive manufacturing is the ability to profitably replenish the supply chain while dynamically responding to supply and demand uncertainties. With global supply chains, the more fragmented the supply chain, the more fragile it is, and the more fragile the supply chain, the more adaptive it needs to be. Even a small disruption can cause expensive problems, so it's crucial (even for a lean six sigma enterprise) to detect these exceptions proactively and dampen them at the source. As Figure 3 shows, adaptive manufacturing provides the necessary flexibility to be responsive in a real-world-aware environment, and it augments the lean six sigma enterprise, creating significantly greater efficiencies.
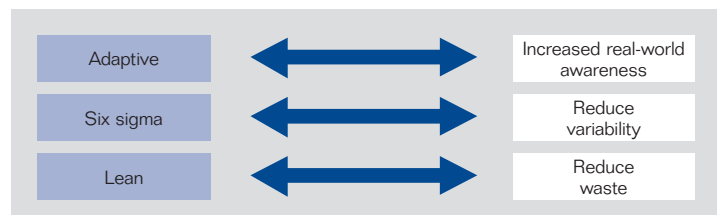
Figure 3: Adaptive Manufacturing Enables the Lean Six Sigma Enterprise

Nothing in adaptive manufacturing goes against the principles of lean manufacturing. In fact, the ability to adapt rapidly and augment lean, pull-based systems that are often more fragile than traditional, push-based systems is what builds efficient manufacturing processes that can withstand a continuous barrage of exceptions.

The Lean Enterprise Must Become Adaptive

As demand variability continues to explode, the ability to postpone production until receipt of a firm order enables late-stage differentiation that is key to keeping costs low. This is easier said than done because businesses have two conflicting objectives:

- Fulfill customer demand within the expected lead time (maximize customer service levels)
- Postpone production until the receipt of a confirmed order (minimize inventory levels)

In any lean manufacturing environment, "pull" is the operative principle. The further back (or upstream) from final product assembly the manufacturing pull-push decoupling point, the greater the adherence to lean manufacturing principles, because it maximizes the length of the pull part of the supply chain. But not all industries require lean manufacturing to the same degree. Different industries use different manufacturing methods, and lean principles do not apply equally to each manufacturing method.

Most manufacturers produce both high-volume goods with steady demand and low-volume goods with fluctuating demand. Typical product mixes include make-to-stock, make-to-order, and engineer-to-order items. Lean thinking today recognizes that only **select** portions of manufacturing can be purely pull (or order) driven. Continual analysis is required to manage complex product mixes that are manufactured based on the volume of production and the complexity of the production mix. Frequently, the decoupling point with a manufacturing line is a tradeoff between the longest lead time a customer is prepared to accept and the production lead time point at which the variability in product demand increases significantly. The push part of the supply chain is primarily forecast driven, whereas the pull (or lean) part is demand driven. The decoupling point or interface between pull and push is also referred to as the point of postponement (PoP).
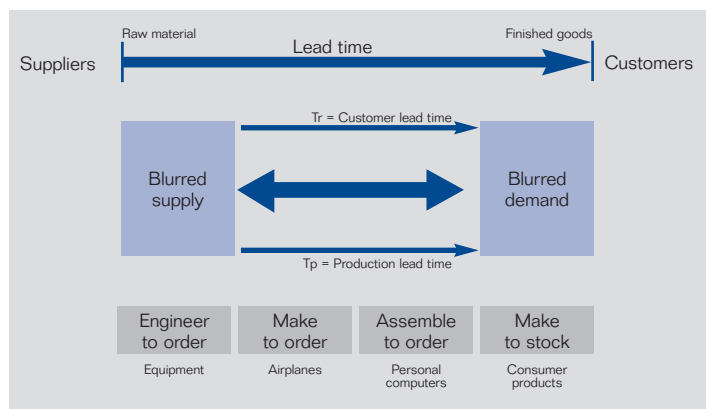
Figure 4: Manufacturing Models and Their Impact on Lead Times

As Figure 4 shows, it's important that the production lead time always be less than the customer's expected lead time. Inventory is held at the PoP boundary to enable a rapid response to customer requests. Typically in a manufacturing environment, a part spends less than 5% of the time in value-added activities. The remaining 95% of the time is spent on non-value-added activities. Reducing the production lead time by eliminating activities that don't add value (waste) and variability in manufacturing operations continuously enable manufacturers to be more responsive and faster to market, while improving asset utilization and asset turns. This is what lean manufacturing principles advocate. Lean manufacturing requires you to move the point of postponement further back into the supply chain. The further back this point, the leaner the operation.

To push the PoP upstream, you need additional visibility and faster cycle times. The greater the visibility across the supply chain, the better your chance of pushing the PoP further upstream. Therefore, it's essential that you define your hybrid manufacturing strategies for different customers and product segments and then align your performance management scheme to each strategy. Once you identify the strategies, the objective of adaptive manufacturing is to continually modify the PoP and successfully push the interface between supply management and customer fulfillment further back in the supply chain (upstream). This minimizes the need for inventory, forecast dependency, kitting, setups, and warehousing, and it allows for efficient late-stage differentiation.

Lean Manufacturing and Six Sigma Drive Management by Exception for Continuous Improvement

Lean principles reduce the lead time of any process and minimize cost from activities that don't add value. Six sigma principles minimize variation and improve yields by following a problem-solving approach based on statistical tools. Six sigma doesn't address the question of how to optimize process flow, and lean principles exclude statistical tools that can institutionalize continuous

improvement. Each principle can individually result in improvement, but their combined impact is far more significant. As Figure 5 shows, lean practices reduce waste by balancing resource utilization, and six sigma techniques provide a structured, fact-based way to achieve continuous manufacturing improvement by identifying the root causes of process variation that impact productivity. Six sigma also sends an alert when there is a violation from process set points. (This is done using control charts, which are discussed in a later section.)

One of the key drivers for the lean and six sigma convergence is the pressure on manufacturing to achieve higher levels of productivity. As long as businesses had the luxury of maintaining spare capacity and excess inventory, they could create an insulation layer for manufacturing and supply chain that helped manage exceptions. But reducing dependency on inventory and capacity by moving the point of postponement back is like lowering the waterline. It exposes rocks, and ships have to be more adept at maneuvering around them. Rocks play havoc with ships, and exceptions play havoc with business. Likewise, the leaner processes become, the more exposed they are to any variability across the supply chain network. In such an environment, six sigma practices provide manufacturing plants with an early warning system for process deviations.

Lean Focus	Six Sigma Focus
Material, effort, time waste	Process variation
Balance flow in manufacturing	Identify root cause of problems
Reduce cycle times	Create uniform process output
Critical to productivity	Critical to product and process quality

Figure 5: The Focus of Lean and Six Sigma Principles

Obviously, leveraging six sigma practices to improve process performance isn't a new concept. But leveraging six sigma practices to enable lean manufacturing processes is becoming increasingly prevalent. Intuitively, this is quite a natural convergence. You accomplish it by identifying the root causes of process variation that impact productivity and by setting up a

mechanism that alerts the appropriate persons when actual values violate process set points. Two of the key enabling capabilities of six sigma that support lean manufacturing include statistical process controls and Pareto diagrams.

Statistical process control applies statistical methods to analyze data, study and monitor process capability, and track variation. Its procedures include:

- **Sampling** – This procedure can be carried out according to ISO 2859-1 or other standards.
- **Dynamic modification of the inspection scope** – This procedure is conducted according to ISO 2859-1 or ISO 2859-1 standards.
- **Control charts** – The control chart monitors the variance in a process characteristic over time and alerts you to unexpected variances that may cause exceptions.
- **Process capability indicator** – This indicator shows the ability of a process to produce parts that conform to specifications. It is related to the inherent variability of the process.
- **Pareto diagrams** – These diagrams focus your efforts on problems that yield the greatest return by tracking the relative frequency in a descending bar graph.
- **Defect measurements** – Defect measurements account for the number or frequency of defects that lead to nonconformance in product and service quality.
- **Root cause analysis** – This analysis isolates the root cause of nonconformance, helping to eliminate it.

These six sigma capabilities track the key forms of waste identified by lean manufacturing principles. Figure 6 identifies the forms of waste identified by lean principles and the associated metrics that are quantified and tracked statistically by six sigma processes.

Lean Forms of Waste	Six Sigma Tracking for Variability Analysis
Overproduction	Inventory, intermediate stocks, labor hours
Waiting time	Parts in queue waiting on upstream jobs
Transportation	Cycle times for material handling and movement
Processing	Rework levels requiring material and labor
Stocks	Inventory level and age, carrying cost, warehousing costs
Motion	Takt time and motion within processes
Defective products	Scrap levels

Figure 6: Correlating Lean Manufacturing and Six Sigma Activities

Six sigma is not just about data collection. Frequently, six sigma teams end up spending a significant amount of time manually collecting data that is too latent and inaccurate. If any gathered data has bias at the source or is subject to interpretation, analyses based on this data may contain errors. Furthermore, manual data collection is prone to mistakes. Therefore, you need a systematic process of data collection that answers three basic questions:
- How accurate is the data?
- How real-time and how relevant is the data?
- How scalable is the data collection process?

To ensure sustainable six sigma programs and to avoid failures from inaccurate data requires stable and scalable information systems to collect data and a functional application system that allows you to analyze and distribute the information. Ideally, these systems should gather data automatically at the source of an activity. For example, they should gather data about yields, conversions, efficiencies, wait times, material availability, and production directly from the shop floor. Direct data gathering minimizes data inaccuracies and errors that result from manual interpretation. You can then distribute this information to either an analysis tool or to an alerting framework.

Given the current variability in business environment, access to and analysis of real-time information is crucial for any lean program. The six sigma approach is integral to any successful lean manufacturing implementation. Once lean manufacturing techniques eliminate wasteful activities, six sigma offers a sequential, problem-solving procedure to continuously measure, analyze, improve, and control the processes, as well as the necessary statistical framework. Working in unison, the two methodologies guarantee a dramatic improvement in productivity.

LEVERAGING ENTERPRISE APPLICATIONS TO ENABLE THE LEAN SIX SIGMA ENTERPRISE

Leveraging ERP to Enable Lean Manufacturing

Most successful implementations of lean manufacturing strongly leverage ERP capabilities. Traditional lean manufacturing techniques by themselves are insufficient to ensure success in the current business environment.

The Challenge for Stand-Alone Lean Manufacturing

Traditional lean manufacturing operations work best in an environment with relatively stable demand, supplier proximity, and low product mix. Because this environment really doesn't exist today, lean manufacturing principles have morphed to maintain the pull philosophy and to adapt to current reality. The traditional lean manufacturing approaches have some limitations:

- Managing high levels of product variety and demand variability while continually stretching the pull part of manufacturing operations despite minimal inventory on hand
- Operating efficiently in a pull-push environment with global suppliers, long lead times, and fragmented manufacturing operations
- Obtaining visibility and adapting dynamically to manufacturing exceptions that could impact the supply chain and vice versa without incurring costs that lower margins

Managing an Environment of High Product Variety and Demand Variability

A lean manufacturing enterprise is driven by the customer demand rate. Manufacturing operations balance the customer demand rate to the takt time. "Takt" is the German word for the baton that an orchestra conductor uses to regulate the speed, beat, or timing at which musicians play. Lean production uses takt time as the time it takes to produce a finished product. For example, a takt time of two minutes means that a complete product, assembly, or machine is produced every two minutes. Therefore, if customer demand is more than two minutes per product, there is insufficient capacity. Alternatively, if customer demand is less than two minutes per product, there is excess capacity.

In the current business environment, demand rates constantly vary, and manufacturing operations need to be continuously rebalanced without destabilizing operations. Moreover, multiple products are frequently produced on the same line, and each of these operations could operate for different periods of time in a day. So while a continuous flow may be feasible in theory, in practice it's often impractical when implemented in isolation with the sole objective of leaning single product lines. The reality is that products flow at multiple takt times through multiple operations, and these activities need to be coordinated simultaneously. In conjunction with ERP, a manufacturing system can be automatically reoptimized (keeping in mind the overall constraints that exist across the supply network) and rebalanced for different takt times when necessary. This approach better supports lean enterprises that must deal with variable demand and high product variety.

Balancing Push-Pull to Enable Lean Manufacturing for the Real World

The idea behind a pull-based system is to minimize inventory and build products at a pace that is precisely mapped to the rate at which customers need products and is as close as possible to when they want products delivered (takt time). Operations that work faster than the takt time build up inventory, which is a waste according to lean manufacturing theory. Operations that run slower than the takt time indicate delays and lead to either lost orders or overtime to catch up.

In theory, the benefits of manufacturing based on takt time are indisputable. In reality, this approach promotes a single piece flow that may not be practical for all products. Many companies have expensive machines, special setup requirements, and labor constraints that can't be justified for single piece flow. Moreover, in demand-driven environments with a global supply chain, customer-side lead times are shrinking faster than the lead time required to procure many raw materials and assemblies. This means that instead of building exactly in the sequence that customers pull products, a mix of actual customer demand and

forecasted demand needs to be spread over a specific time horizon, and manufacturing needs to build to that leveled demand. When combined with ERP, lean manufacturing techniques provide the flexibility required of this traditional push and desired pull-push hybrid model. Traditional push methods include material requirements planning (MRP), reorder points, and optimum order quantities. Push-pull methods include kanban, backflushing (or component inventory management), and back-to-back orders for single piece flow – capabilities provided by some ERP solutions.

Higher Visibility:

A Management by Exception Requirement

The leaner the system, the greater the need for mutual visibility between manufacturing and the supply chain to dynamically manage exceptions. Exceptions are a daily reality. If you don't manage them proactively, exceptions can lead to considerable loss in productivity. The leaner the operation, the greater the impact of exceptions.

Kanban cards provide visibility across a traditional lean manufacturing operation. Kanban cards can enhance the visibility of material flow on the plant floor, but the system has limitations, especially in situations with severe demands on flexibility that lead to more exceptions. In a typical kanban system, information propagates only upstream as parts get consumed down the line. The kanban system by itself can't anticipate exceptions or disturbances, so it needs to be a part of an overall manufacturing execution system that can sense and then manage exceptions. Manufacturing execution requires you to continuously capture all kinds of data (operator comments, product quality information, and the like) and then compare and monitor operations while providing visibility into this information to all relevant players.

With pressure from demanding customers with high expectations for service, any disruptions (unavailability of parts, machine breakdowns, absenteeism, or deviations from operational excellence) need to be identified and all affected parties alerted.

Adapting manufacturing to these disruptions requires collaboration with other business functions – purchasing to procure parts from alternate sources, maintenance to repair machines, human resources to find workers with the required skills, transportation to coordinate shipment, and accounting to invoice customers and collect payments. ERP systems contain much of the information required to respond to changes. As the nature of customers, competition, and product mix changes, you must continuously update manufacturing strategies and business workflows to reflect the new manufacturing environment. Data integrity also needs to be maintained. Current ERP systems offer configurable, user-defined workflows. They can be wired to the shop floor, and they can react rapidly to manage exceptions.

Leveraging ERP to Enable Six Sigma

As lean manufacturing and six sigma become intertwined, ERP is helping to enable six sigma operations and lean manufacturing. You need information to understand variability so a six sigma initiative needs enterprise information from your ERP system. ERP capabilities greatly enhance six sigma processes. Figure 7 shows the benefits you can achieve with just a one sigma (one standard deviation) improvement in manufacturing. Almost all the information necessary to measure these metrics comes from ERP systems, so ERP is the backbone for any six sigma program.

One Sigma Increase In	Yields (Percent Improvement)
Margin improvement	20%
Increase in capacity	12%–18%
Reduction in employees	12%
Reduction in capital expenses	10%–30%
Source: *Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations*, by Mikel Harry and Richard Schroeder (Doubleday, 2005)	

Figure 7: Benefits of a One Sigma Improvement

The Challenge for Stand-Alone Six Sigma

A six sigma manufacturing operation needs the ability to measure current performance, analyze operations, and identify opportunities for improvement (see Figure 6) by providing alerts when performance approaches set thresholds (for example, when aggregate or individual product quality levels drop below set limits). The more near real time these measures, the greater the benefits. Current six sigma practices in manufacturing operations present challenges because to make it work you must:

- Obtain accurate and near-real-time data for analysis of manufacturing and supply chain operations by leveraging a scalable architecture that minimizes need for human intervention for data collection
- Create an alerting framework that can track complex interactions through statistical processes and control charts so you can institutionalize the monitoring, measuring, analysis, improvement and control workflows

**The Need for Accurate Data
and a Scalable, Zero-Latency Architecture**

As a structured, fact-based approach to continuous improvement, six sigma programs need accurate data to analyze current performance issues and their root causes. To accomplish this, they require an architecture that enables automated data collection. Manual data collection is an error-prone, tedious process that usually depends on the dedication of the individual driving the six sigma program. And the longer the time between the end of operational activities and the six sigma analysis, the more likely the chance of a delayed recognition and response to any exception – a common problem with manual data collection.

Successful six sigma programs require a good information system that minimizes manual data collection from multiple sources and then attempts to draw inferences. In many cases, a six sigma project begins with improvement at a single workstation or an assembly line. This typically expands to an effort to scale the improvement to an entire factory or supply chain level because the root cause for the original problem may be distributed across many functions. In fact, to reap substantial

benefits, you may need to scale to the business level and correlate data from the plant floor, suppliers, customers, and other parts of your supply chain. Systematically capturing such data with minimal latency, along with data in the ERP system, builds the foundation for a successful six sigma program. For example, in a manufacturing environment, connecting to a plant allows you to collect detailed data about productivity, conversions, quality, and yields. Then you can correlate this data with other parameters, such as inventory levels, margins, costs, and process conditions. In fact, in some industries, data collection must be automated to ensure compliance with regulations. Without an ERP system in place, managing this information is a data integration nightmare.

**Analyzing Complex Interactions
with Business Intelligence**

Data collection is important, but it's just the first step of a six sigma program. The next step is to analyze the data using statistical process analysis and control charts to drive improvement.

Consider product costing. Variables like material cost, labor cost, and utilities costs determine the cost of a product and its overall margin. But operating variables like conversions and yields are also necessary. Tracking these variables collectively and individually (and frequently) gives you insight into the accuracy of product costs and a better understanding of the individual variables. Understanding these individual variances helps you drive improvement programs and set new targets for continuous improvement.

Historically, six sigma teams have created stand-alone reports and then compared data across reports to infer relevant information. By deploying a good ERP system with a business intelligence system, these manual processes become less necessary, and it becomes easier to analyze complex relations among the variables.

SAP: ENABLING THE ADAPTIVE LEAN SIX SIGMA ENTERPRISE

A well-implemented ERP system is the foundation on which to build an effective lean six sigma program. The mySAP™ ERP solution provides capabilities that are core to the success of lean six sigma initiatives: common work processes, real-time data sharing, application integration, data integrity, inventory visibility, available to promise (ATP), capable to promise (CTP), real-time order management, proactive exception management, business intelligence, and analytics. By leveraging the principles of waste reduction and variability analysis, initiatives that combine the benefits of lean, six sigma, and ERP principles deliver value not just in manufacturing, but also to the business areas that are integrated into manufacturing. These benefits are enabled by:

- Automating and integrating manufacturing with other core business processes to reduce waste and reduce cycle times
- Sharing common data and information from manufacturing across the enterprise to enable a single version of the truth
- Speeding the consolidation of manufacturing operations and financial information to analyze the impact of actions on margins
- Producing and accessing information in real time to proactively react to and dampen the impact of exceptions

Adding lean manufacturing and six sigma capabilities to the mix magnifies these benefits, and SAP provides solutions that combine these capabilities.

SAP® Manufacturing: Lean Capabilities

As we mentioned earlier, products rarely fit into one neat production environment. Even within lean manufacturing, most manufacturing facilities use a mix of manufacturing methods, and they may use the same raw materials to make multiple products. These plants can use a blend of push and pull material planning and control methods to ensure that they produce products when they are needed while adhering to lean principles. SAP® software supports a broad range of lean manufacturing techniques, including flow manufacturing, demand-driven manufacturing, make-to-order processes, and advanced repetitive manufacturing. To enable these pull-based

methods, SAP software also supports various types of kanban techniques. Most of these capabilities are embedded in the mySAP ERP solution. Some of the advanced planning capabilities are available in the SAP Advanced Planning & Optimization (SAP APO) component. A significant benefit is the tight integration of the lean manufacturing capabilities with other solutions in the mySAP Business Suite family of business solutions, including: mySAP Supply Chain Management (mySAP SCM), mySAP Customer Relationship Management (mySAP CRM), mySAP Supplier Relationship Management (mySAP SRM), and mySAP ERP Financials.

Flow Manufacturing

In flow manufacturing, customer demand triggers the pull of production through the system. SAP capabilities for flow manufacturing include line design, line balancing, demand management, line sequencing and model-mix planning, lean execution, backflushing, and kanban management.

These capabilities are based on integrated product and process engineering functions. SAP software integrates engineering design activities with those of manufacturing engineering – consistent with lean principles – by avoiding unnecessary iterations across functional boundaries and accelerating product development and time to market.

SAP software supports advanced planning and material flow concepts and, in addition to providing a common database for design, engineering, production planning, and costing, plus great flexibility and responsiveness via rapid planning capabilities, SAP also incorporates support for state-of-the-art, best-practice lean manufacturing for various industries, including line balancing and takt-based scheduling:

- Line design capabilities depict individual production lines, linear networks, and highly complex networks with alternative lines so you can balance interlinked assembly lines and optimize work on individual line segments. These capabilities are suitable for repetitive or flow manufacturing with takts where workstations are linked in place and time. SAP software also supports takt-based scheduling.

- With takt-based scheduling capabilities, you can calculate order lead time by multiplying the number of takts by the takt time. You can create capacity requirements for line resources. In flow and repetitive manufacturing, materials remain for the defined takt time of the in-process line. Takt-based scheduling produces a more exact result than lead-time scheduling based on exploded order routing diagrams.
- Line balancing capabilities reconcile time requirements and capacity. You can assign activities to line segments so you can complete activities with a predetermined takt time.

Just-in-Time and Just-in-Sequence Capabilities
In discrete manufacturing environments like the automotive industry, you can use summarized and sequenced JIT calls for requirement call-offs among OEMs, suppliers, and sub-suppliers. These techniques help reduce lead times, cut quantities on hand, and optimize costs between OEMs and suppliers by nearly eliminating picking and storing costs. The JIT and just-in-sequence (JIS) capabilities of SAP software support lean manufacturing methodologies by enabling call-offs to optimum needs to reduce lead times and stock levels. SAP software supports different flavors of JIT and JIS.

Summarized outbound JIT calls support production and material flow control based on physical material stock in production. Material that is required regularly (with short delivery times) is kept available in lean quantities for production. Replenishment is triggered directly in production once a certain quantity of the material has been consumed. Using the summarized JIT call capability of SAP software, production assumes control of the production process, which reduces posting effort. The benefit of this self-control is shorter lead times and lower stock levels. You can use outbound summarized JIT calls for external replenishment when material is procured from an external vendor and for stock transfer from warehouses for internal transfers.

Suppliers use summarized inbound JIT calls to ship materials in lean quantities based on call-offs from customers that specify the date and quantity required. These items don't have any reference to the finished product, and they aren't delivered in sequence. The summarized inbound JIT calls capability of SAP software support the complete supplier process and handle real OEM requirements and shipping instructions.

SAP offers another type of sequenced JIT calls (also called order-based JIT calls) for companies that need sequenced JIT calls when a supplier ships fully configured components, both with reference to an order and in sequence. Order-based JIT calls support the entire business process, from the receipt of the forecast signal right up until the creation of the delivery and, if necessary, delivery confirmation.

Demand-Driven and Make-to-Order Manufacturing
SAP software supports push-pull logic with a combination of demand-driven manufacturing and make-to-order (MTO) techniques, complemented with plan or manufacture-to-PoP techniques. Examples of this support include:
- MTO for OEMs
- MTO with component availability checking
- MTO with capacity checks
- MTO with multiple output planning (MOP)
- PoP planning at the assembly or component level

SAP solutions for MTO environments support non-configurable products, configurable products, and engineer-to-order products. SAP manufacturing solutions support assembly processes in repetitive manufacturing environments, as well as assembly in shop-floor environments with production orders. For all MTO processes the visibility of the customer order (achieved with order pegging structures during planning and execution) is key. Here's a closer look at some MTO capabilities:
- **MTO for OEMs** – You can plan and execute production quickly and efficiently in environments with multiple variants and large numbers of orders. SAP capabilities include

order scheduling, time-specific calculation of component requirements, date-specific procurement of components, and backflushing.

- **MTO with component availability checks** – This capability meets the specific production requirements of manufacturers of configurable products. The software triggers a component availability check for a requested product as soon as the sales order is entered into the system. It immediately identifies missing components and determines the earliest possible delivery date. Using the multilevel ATP function in SAP APO, you can perform fast and reliable component-level availability checks. This capability is particularly suitable for configurable products, such as personal computers or other products from the high-tech or machinery industries.

- **MTO with capacity checks** – With this capability, you can trigger the production of a requested product at the moment the sales order is entered into the system. The software automatically checks machine capacity, schedules production, and determines the availability date of the requested product so you can immediately make reliable offers and commitments. This feature addresses the requirements of MTO manufacturers, including the high tech and mill products industries.

- **MTO with multiple output planning (MOP)** – MTO with MOP is a three-stage production capability that runs from the raw material to the semifinished product and finally to the finished product. It is an MTO capability, so there is no available stock at the finished product level. Production begins as soon as a requirement is created. You can split, cut, or divide a product into several other products during production. The software optimizes the process of selecting product receipts or warehouse stock with characteristics to cover requirements. Any offcuts that are produced when a product is split can be determined using MOP and assigned characteristics. You can then use offcuts to cover other requirements.

- **PoP planning and planning at the assembly (or component) level** – This capability enables component-level ATP, which provides ATP information to CRM systems. It is used in MTO environments where the enterprise must plan and manufacture or procure intermediate assemblies or compo-

nents, but must wait for a customer order to specify the final assembly. This capability enables you to procure the raw materials and manufacture components to PoP levels in the bill of materials (BOM) structure. After the customer specifies a configuration, the final product is assembled, and the manufactured product is shipped to the customer. Assembly-level planning helps reduce the lead time on sales orders and provides the flexibility to meet exact customer requirements.

The PoP planning method is set in the BOM structure by designating BOM levels as nettable or non-nettable, phantom or non-phantom. Nettable, non-phantom levels are the level at which further processing is postponed and the level at which assemblies or components are planned, enabling component-level ATP. The ATP date of the manufactured product is set as a function of the component with the longest lead time. Selecting the BOM level where PoP occurs depends upon the required lead time you must be able to quote and execute for your customers. If the customer lead time is longer than the cumulative lead time to procure components and assemble the product, then the PoP is at the lowest component level. This includes situations in which suppliers hold component inventory until called off from a contract order. If the customer lead time is shorter than cumulative product lead time, then you must establish the PoP at the level of the BOM structure where remaining cumulative assembly or fabrication lead time is less than the required customer lead time.

Advanced Repetitive Manufacturing

Repetitive manufacturing capabilities are designed for manufacturers that build or assemble products daily or frequently. You can control manufacturing processes through production schedules rather than traditional shop orders, and you can schedule work by production line by day without formal work orders. This is a rate-based, lean production control system. Based on production and assembly lines, takt times are used for scheduling. You can use optimization algorithms and heuristics for model-mix planning and line balancing. The software considers continuous input and output during scheduling. The

production runs without any orders for run schedule quantities and production versions. Backflushing of labor and material at reporting points supports lean execution. Advanced repetitive manufacturing capabilities enable suppliers and OEMs with high volumes of data to increase production efficiency and responsiveness. SAP APO is used to achieve these goals, and manufacturing execution takes place in mySAP ERP.

Support for Kanban Techniques

SAP also supports a variety of kanban techniques that are used in pull-based systems. These include:

- **Classic kanban** – This is the demand source, supply source, replenishment procedure, the number of kanbans that can circulate, and quantity per kanban defined in the control period or cycle.
- **Event-driven kanban** – A material provision based on actual material consumption rather than a predefined number of kanbans or predefined kanban quantity. Material is replenished only when specifically requested, not continually.
- **One-card kanban** – A one-card kanban system with two kanbans in a control period or cycle has replenishment triggered when the container being replenished is about half empty. A new kanban is delivered before the container is empty. This technique helps you reduce inventory at the demand source during periods when material is not required.
- **Kanban with quantity signal** – With quantity-signal kanban, you directly enter individual withdrawn quantities into the system. The solution enters the individual withdrawal quantities from the actual kanban quantity and when the kanban quantity is zero, the software automatically sets the status of the kanban to *Empty*. This differs from classic kanban in which the kanban capability sets the status of the kanban and the system isn't informed of the quantity still in the kanban until the status is set to *Empty*.
- **Kanban replenishment with MRP** – Materials are planned in the planning run and corresponding procurement proposals are created. Instead of directly triggering replenishment, procurement proposals provide a preview of future consumption. The kanban signal triggers replenishment.

- **Kanban replenishment without MRP** – Only the kanban signal triggers replenishment for certain materials. These materials aren't planned in the planning run, but you can include them in long-term planning.
- **External procurement with Internet kanban** – Using Internet-based kanban, a vendor can request information about empty containers directly over the Internet. The vendor has a clear overview of the product stock in all relevant control cycles and can determine which quantities of a product must be delivered. This type of replenishment transmission is an alternative to sending the vendor the kanban (the card) or another form of order or giving the vendor kanbans for empty containers if the requested containers are delivered. The vendor can also set the status of the kanbans to deliver to *In Process* directly over the Internet. In this way, customers find out which kanbans will arrive with the next delivery. You can evaluate product stock with the vendor, compile delivery due lists, and confirm delivery quantities at any time of day and all over the world.

Safety Stock and Buffer Planning

SAP capabilities for buffer stock planning include reorder point and safety stock planning. These capabilities support the lean inventory management objective of striking a balance between high customer service and minimal inventory levels.

In reorder point planning, replenishment is triggered when the sum of plant stock and firmed receipts falls below the reorder point. The reorder point is set at a level sufficient to cover the average material requirements expected during the replenishment lead time. The reorder point is determined by the safety stock values and average consumption over the replenishment lead time. You can set the reorder point manually, or the software can automatically determine it. With automatic reorder point planning, an integrated forecast program uses historical data to forecast future requirements. The software then uses these values to calculate the reorder and safety stock levels, taking the service level and the materials replenishment lead

time into consideration. The software continuously adapts reorder levels and safety stocks to the current demand and delivery situation.

Safety stock exists to cover both excess material consumption within the replenishment lead time and any additional requirements that may occur because of delivery days. The reorder level includes safety stock. SAP supports two safety stock planning methods: standard and extended. Standard safety stock planning methods are mainly based on planners' experience. With standard safety stock planning methods, you manually enter the safety stock level, which can be static (same value over time) or dynamic (varies over time). The other elements of the standard safety stock method, safety days supply and the maximum safety stock level or maximum safety days supply, may also be static or dynamic.

With extended (automatically established) safety stock planning, the software generates safety stock-level proposals based on scientific safety-stock-planning algorithms. The algorithms' starting point is the service level – the sigma value or degree of probability to be established that customer demand can be met. The service level can be defined by shortfall events (alpha service level) or shortfall quantities (beta service level), and the stockholding method can be based on the reorder cycle or reorder point method.

Customer and Supplier Collaboration Planning

Today lean manufacturing extends beyond the manufacturing plant. Successful companies will extend lean manufacturing techniques upstream and downstream in the supply network to suppliers and customers.

The customer-side collaboration capabilities of SAP solutions address the need for better visibility into demand signals, fully automated replenishment processes, and the ability to work more efficiently on promotion management. Compared to supplier collaboration processes, customer collaboration is more focused on automating cross-company processes between

companies and on efficient data exchange and process synchronization between trading partners. Typically, every company in the network owns its own applications and shares information on forecasts, POS data, and inventory over the Web. SAP solutions can also automatically exchange this information, automatically alerting planners of any missing or incorrect data. Using the error-free data, the software executes forecasting, replenishment, and fulfillment planning. Orders are created and sent out to internal and customers' ERP systems.

For supplier collaboration, SAP provides an exception-based capability that allows suppliers to see the status of their materials at manufacturers' plants, receive automatic alerts when inventory levels get low, and respond quickly via the Web. Manufacturers can also implement industry-standard replenishment processes, such as supplier-managed inventory (SMI), which is based on gross demand and min-max stock balances and other net demand processes, such as release and purchase-order-based processes.

SAP Manufacturing: Six Sigma Capabilities

Six sigma is all about data and measurement. IT establishes metrics that align an organization's strategic goals and values with customer needs and expectations. The higher the sigma value, the lower the variation and, therefore, the fewer the defects or exceptions. This principle is as simple as it is complex. In many areas, six sigma performance (3.4 defects per million opportunities or operations) may not be relevant, and it may suffice to continually raise the sigma rating. For instance, it is unreasonable to expect cycle time performance for an auto assembly line to fall under a six sigma band, and it may be more pragmatic to raise it from a four sigma to a five sigma level. We reference six sigma processes, but the same equally applies to other sigma levels of improvement.

The DMAIC Process

DMAIC refers to a data-driven quality strategy for improving processes. It is an acronym for five interconnected and cyclical phases: define, measure, analyze, improve, and control. Each step in the DMAIC process is required to ensure the best results. The process steps are as follows:

Define:
- What are the objectives for the improvement?
- Which processes need to be improved to meet the objectives?
- What are the boundaries for the process improvements?
- What are the key performance indicators and the expected benefits?
- What will the execution process be?

Measure:
- What is the data collection plan?
- What and how many types of defects or errors are produced?
- What is the performance level of the product or process?
- Is the variation within normal range?
- Which functional areas are most affected?

Analyze:
- What are the gaps between current performance and the target?
- What are the major sources of variation?
- Which root cause has the biggest impact?
- How often do the exceptions occur?
- How likely is it that a customer will be affected?

Improve:
- How real is the variation observed?
- Is the measurement system timely and adequate?
- How manually intensive and error prone is the analysis process?
- Which improvement idea represents the largest payback?
- What is the expected benefit for moving to the next level?

Control:
- How can I ensure the improvement is permanent?
- Are the benefits repeatable and documented?
- What monitoring system is in place?
- How are the best practices shared with other teams?
- How are the benefits reflected in the next business plan?

SAP software supports the DMAIC cycle and helps you implement processes to institutionalize improvement and statistical control charts to track performance across business processes.

Six Sigma Project Management Capabilities

Based on the requirements of the DMAIC process, two principal, integrated capabilities are necessary: a tool set for managing the DMAIC process steps and an analytical tool set. SAP software provides a wide range of capabilities that support the DMAIC process or subsets of the process. These capabilities include project management, analytics, and control tracking. SAP software also provides project management and process capabilities that support six sigma programs.

The Collaboration Projects (cProjects) suite defines the scope of a six sigma project and assigns the phases, resources, targeted results, and the relevant documentation. cProjects also addresses six sigma design principals (design for six sigma or DFSS). Specifically, cProjects supports:
- Design failure mode and effect analysis (DFMEA)
- Process failure mode and effect analysis (PFMEA)
- Control plans to define the control parameters to be analyzed during production

You can use cProjects to collaboratively manage six sigma projects. cProjects also enables:
- Document management to describe and document the project results and to provide six sigma report templates that include the required process maps and flow charts
- Audit management for evaluation and planning and for executing various kinds of assessments, audits, and surveys, both internally and externally. Audits help to capture internal and external exceptions, risk assessments, and benchmarks.
- Quality notification capabilities that help with the data recording to capture, describe, evaluate problems, and identify defects and their causes, as well as to implement corrective and preventive actions
- Inspection tools that help with data records to evaluate inspection results for critical characteristics using statistical tools and metrics

Six Sigma Analytical Capabilities

SAP provides capabilities for sophisticated analytical analysis, Pareto analysis, and graphical control charts that you can use to control, analyze, and document manufacturing processes.

Analytical needs are addressed by SAP's business intelligence (BI) capabilities, including a data warehouse that converts the captured data into information and ensures information is delivered at the right time to the right person in the right format for six sigma decision making. This holistic capability includes data acquisition (from the shop floor, partner applications, supply chain applications, and so on), data warehousing, online analytical processing (OLAP), a planning framework, BI tools, role-based dashboards, and analytical applications with preconfigured content using best-practice models. SAP's analytical capabilities are in many ways unique because they address core issues that severely affect six sigma initiatives:

- **Data spread over different systems** – In such an environment, analysis is time-consuming and sometimes inconsistent.
- **Irrelevant information** – Poor data forces decision makers to waste time finding relevant, timely information before they can even analyze it.
- **Dependency on IT** – Users require programming knowledge to retrieve information from transactional systems so they can't run ad hoc analyses.
- **Missing business process support** – The appropriate individuals aren't notified of process exceptions.

The ability to collect data, make it centrally accessible, and then mine it is what enables the "analyze" step of the DMAIC cycle. Business intelligence capabilities provide an analytical framework that helps you look for hidden data patterns and relationships in large databases; you develop insight by analyzing past data. You can also predict future trends and customer behavior

(for example, by analyzing the forms of waste in Figure 6). This enables prospective decision making for the "improve" part of the DMAIC cycle as opposed to a pure retrospective analysis. SAP software's data mining capabilities include decision-tree classification analysis, clustering analysis, association analysis, approximation scoring, Pareto analysis, and ABC classification analysis.

Six Sigma Statistical Process and Control Chart Capabilities

The control chart is the central element of statistical process control (SPC). Control charts determine if the processes being executed are under statistical control and, if not, the degree of variation. SAP software provides various types of control charts that you can use to control, analyze, and document the processes involved in manufacturing and other quality-relevant areas. You use control charts to detect systematic deviations of a quality characteristic from a target value (a signal) against the background of inevitable, random fluctuations in individual measured values.

SAP also supports other tools. For example, you can use Western Electric rules and capability indices to analyze measured values. For highly sophisticated mathematical analysis of measured values (like correlation or distribution analysis) SAP offers an interface to external subsystems. You can use a Pareto analysis of types and causes, as well as weighting nonconformities to analyze problems. SAP software can also indicate the existence of related problems and refer them to the appropriate persons for action.

Control charts are primarily used in manufacturing inspections to monitor and manage controlled production processes. A process is controlled or under statistical control if observed process parameters only vary randomly from sample to sample. You can

use the control chart to detect special influences on the process. Control charts can determine whether a process is or was in control or not, even if it's too late for corrective intervention. Control charts can also be used for procurement and dispatch (for example, for incoming inspections based on a scheduling agreement with periodic release orders).

Control charts are integrated with inspection functions, and you can define whether to run a control chart for inspection characteristics during inspection planning. You can run control charts within an inspection lot or a production order, or you can run charts for several inspection lots or production orders. You can also display them and update them when recording results or using a separate transaction. In addition, SAP software can calculate the action limits and warning limits (if necessary) in the control chart window. If there are violations (for example, if a sample is rejected because it violates a limit defined in a control chart), the software can automatically trigger a workflow based on defined defect codes in the inspection plan characteristic.

SAP software provides run charts in addition to control charts. A run chart, a graphic similar to a control chart, displays a chronological curve of the measured values or sample mean values for a selected characteristic. Unlike control charts, run charts don't contain action limits. Instead, they contain limits for the tolerance range and can be used within an alert framework if necessary. You can call up run charts during results recording and when making evaluations, without making any prior settings in the basic data. The following control chart types are available for inspection characteristics:

- Mean value chart with tolerances (acceptance chart)
- Mean value chart without tolerances (Shewhart chart)
- Standard deviation chart (Shewhart chart)
- Moving mean-value chart

- Exponentially weighted moving average (EWMA) chart
- Original value and moving range chart for sample size n = 1
- NP chart for the number of nonconforming units
- P chart for the fraction of nonconforming units
- C chart for the number of defects
- U chart for the number of defects for each sample unit

Proactive Asset Maintenance Capabilities
In the real world, manufacturing lines go down because of machine defects or maintenance issues. Because the core tenants of lean manufacturing and six sigma principles are minimizing waste and reducing variability, a downtime allowance isn't built in. You need a real-world-aware, predictive, and preventive maintenance strategy to adapt to unforeseen events and optimize asset effectiveness. This strategy requires a knowledge-based approach that uses real-time performance and condition information from numerous plant processes and equipment, including sensors, physical processes, controllers and loops, equipment, processing units, and entire plants.

The SAP Service and Asset Management solution provides complete, end-to-end integrated capabilities for enterprise asset management. This solution provides everyone involved in the asset service network real-time visibility on asset performance and maintenance issues for real-time awareness. Real-world awareness enables a proactive response and rapid correction of problems. Enterprise asset management helps you manage physical assets – production plants, capital equipment, vehicle fleets, and facilities complexes – over the complete asset life cycle. With powerful reporting and analysis capabilities, you can reduce operating costs, better manage capital expenditure, and improve asset utilization. These elements are key in implementing the six sigma DMAIC processes.

SUMMARY

Demanding customers expect more innovative products of greater variety delivered with shorter lead times and at competitive price points as a basis for their loyalty. Companies deploying traditional lean manufacturing and six sigma approaches to manufacturing have to deliver these expectations – because of higher demand variability and inability to balance push and pull environments – and sense and respond to unforeseen demand and supply exceptions in the factory and supply chain. An integrated, adaptive lean six sigma approach is imperative to respond to these real-world challenges and demands:

- A lean manufacturing solution enabled by six sigma capabilities makes manufacturing operations more efficient.
- Core to success is the degree of integration into ERP to elevate the lean manufacturing and six sigma initiatives from localized efforts to a more scalable and all-encompassing process that drives significant benefits across supply networks.
- This combination needs to be supported by a scalable technology platform that includes data acquisition, data warehousing, OLAP, planning framework, BI tools, dashboards, and analytical applications with preconfigured content.

With little control over prices and increasing commoditization, the only major option for manufacturers is to cut costs to maintain (or grow) margins for most product lines. To build a truly adaptive manufacturing environment, you must be able to cost-effectively adapt to exceptions – both within manufacturing and across the supply network – while leveraging lean manufacturing and six sigma best practices.

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